



Hybrid Power Management (HPM)

Dennis J. Eichenberg
Glenn Research Center, Cleveland, Ohio

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Dennis J. Eichenberg
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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Dennis J. Eichenberg
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Summary

The NASA Glenn Research Center's Avionics, Power and Communications Branch of the Engineering and Systems Division initiated the Hybrid Power Management (HPM) Program for the GRC Technology Transfer and Partnership Office. HPM is the innovative integration of diverse, state-of-the-art power devices in an optimal configuration for space and terrestrial applications. The appropriate application and control of the various power devices significantly improves overall system performance and efficiency. The advanced power devices include ultracapacitors and fuel cells. HPM has extremely wide potential. Applications include power generation, transportation systems, biotechnology systems, and space power systems. HPM has the potential to significantly alleviate global energy concerns, improve the environment, and stimulate the economy.

One of the unique power devices being utilized by HPM for energy storage is the ultracapacitor. A capacitor is an electrical energy storage device consisting of two or more conducting electrodes separated from one another by an insulating dielectric. An ultracapacitor is an electrochemical energy storage device, which has extremely high volumetric capacitance energy due to high surface area electrodes, and very small electrode separation. Ultracapacitors are a reliable, long life, maintenance free, energy storage system.

This flexible operating system can be applied to all power systems to significantly improve system efficiency, reliability, and performance. There are many existing and conceptual applications of HPM.

Introduction

The central feature of HPM is the energy storage system. All generated power is sent to the energy storage system, and all loads derive their power from the energy storage system. There can be multiple power sources, each optimized for a particular operating condition. There can be multiple loads as required, each connected to the energy storage system. A hybrid power management controller maintains optimal control over each of the components of the entire system. This flexible operating system can be applied to all power systems to significantly improve system efficiency, reliability, and performance.

An HPM energy storage system must be extremely reliable, have an extensive life, and must have a very high efficiency, since all generated power is sent to the energy storage system and all loads derive their power from the energy storage system. The ultracapacitor is an ideal candidate for an HPM energy storage system. Ultracapacitors have many advantages over batteries.

- Batteries can only be charged and discharged hundreds of times, and then must be replaced. Ultracapacitors can be charged and discharged over 1 million times. The long cycle life of ultracapacitors greatly improves system reliability, and reduces life-of-system costs.

- Long ultracapacitor life significantly reduces environmental impact, as ultracapacitors will probably never need to be replaced and disposed of in most applications.
- The environmentally safe components of ultracapacitors greatly reduce disposal concerns.
- High ultracapacitor power density provides high power during surges, and the ability to absorb high power during recharging. Ultracapacitors are extremely efficient in capturing recharging energy.
- Ultracapacitors are extremely rugged, reliable, and maintenance free.
- Ultracapacitors have excellent low temperature characteristics.
- Ultracapacitors provide consistent performance over time.
- Ultracapacitors promote safety, as they can easily be discharged, and left indefinitely in a safe discharged state.

HPM has been successfully applied to the NASA Hybrid Electric Transit Bus (HETB) project (ref. 1). This is a 40-ft transit bus with a unique hybrid drive. At over 37,000-lb gross weight, this is the largest vehicle to ever use ultracapacitor energy storage. The ultracapacitor technology utilized for the HETB is being applied to satellite actuation to replace unreliable hydraulic systems. The motor and control technology utilized for the HETB is being applied to space power systems.

HPM has been utilized to provide power for drop tower research. HPM is being considered for space missions, such as the exploration of the moon and Mars, and deep space missions, such as the exploration of Europa.

Through the NASA Glenn Research Center Technology Transfer and Partnership Office, HPM is being applied to power generation, transportation, safety, and biotechnology systems. Some specific examples include photovoltaic power generation, electric vehicles, and safety systems. Through the Exploration Office, HPM is being applied to the next generation of space vehicles, rovers, and surface power systems.

Objectives

The objective of HPM is to improve power system efficiency, reliability, and performance for a wide variety of space and terrestrial applications. Applications include power generation, transportation systems, biotechnology systems, and space power systems.

Discussion

Peak power requirements of most loads are many multiples of their steady state value. This requires a power source large enough to handle the peak power requirement. An excessively large power source reduces system efficiency. The severe nature of transient loads reduces power system life and reliability. HPM can significantly improve power system efficiency, life, reliability, and performance.

The unique aspects of HPM are indicated clearly in the HPM system diagram shown in figure 1. The central feature is the energy storage system, in which an ultracapacitor is an ideal candidate, due to its long cycle life, high reliability, high efficiency, high power density, and excellent low temperature performance. All generated power is sent to the energy storage system, and all loads derive their power from the energy storage system. The system readily accommodates multiple power sources and multiple loads. A hybrid power management controller maintains optimal control over each of the components of the entire system.

HYBRID POWER MANAGEMENT (HPM) System Diagram

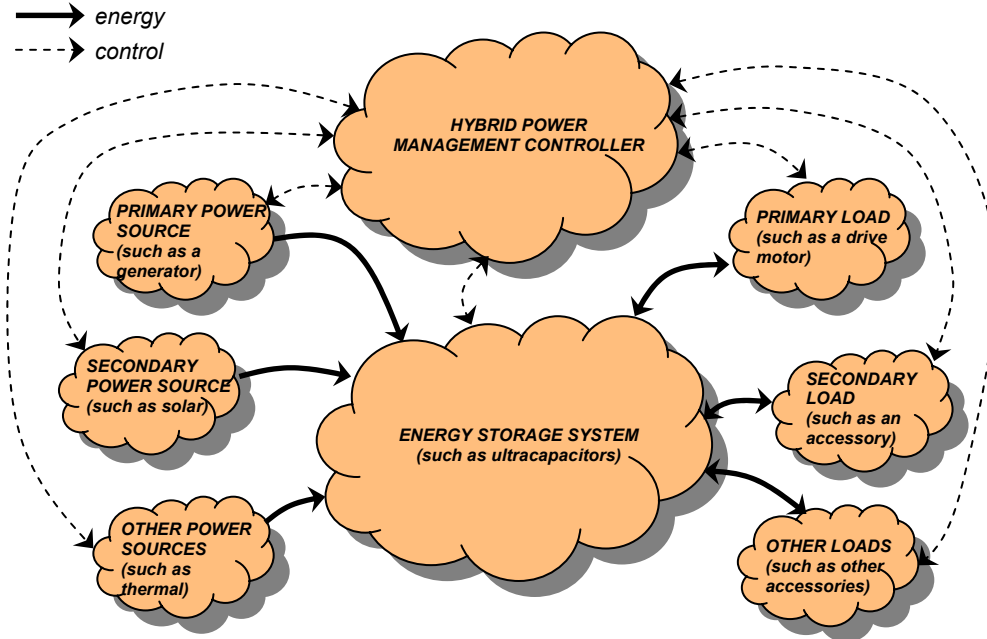


Figure 1.—A system diagram of Hybrid Power Management (HPM).

HYBRID POWER MANAGEMENT (HPM) A Human Analogy

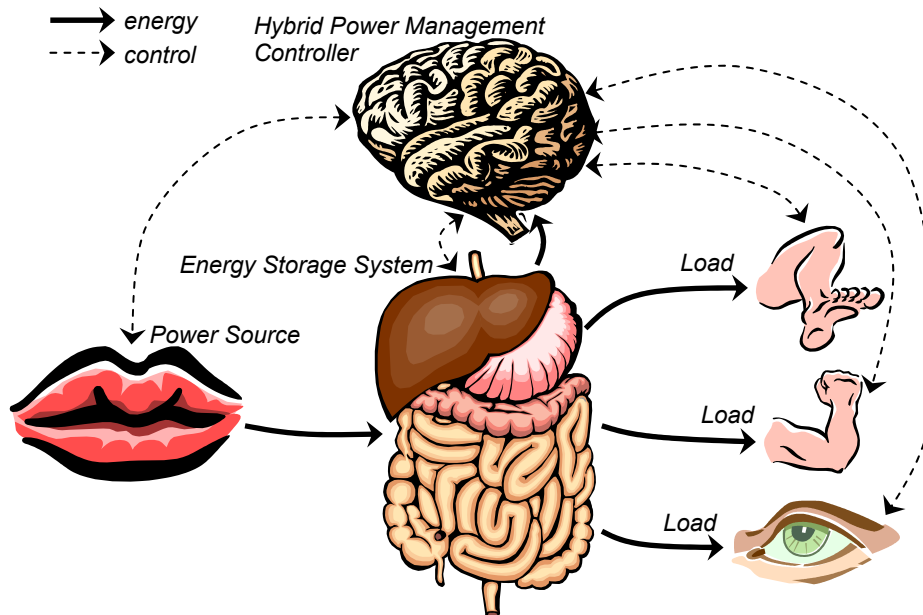


Figure 2.—A human analogy of Hybrid Power Management (HPM).

Greater understanding of HPM can be achieved through a comparison to the human physiology as indicated in the HPM human analogy diagram shown in figure 2. The central feature is the energy storage system, which is the stomach in the human case. All generated power is sent to the energy storage system, and all loads (muscles) derive their power from the

energy storage system. There can be multiple power sources, each optimized for a particular operating condition. There can be multiple loads as required, each connected to the energy storage system. The brain serves as the hybrid power management controller to maintain optimal control over each of the components of the entire system.

Applications

HPM has been applied very successfully to numerous space and terrestrial applications with various governmental and commercial partners, and there are many new applications underway. Some of these applications are described below. Through the NASA Glenn Research Center's Technology Transfer and Partnership Office (TTPO), HPM is being applied to power generation, transportation, safety, and biotechnology systems. Some specific examples include photovoltaic power generation, electric vehicles, safety flashers, and power tools. Through the Exploration Office, HPM is being applied to the next generation of space vehicles, rovers, and surface power systems.

NASA Hybrid Electric Transit Bus (HETB)

HPM has been successfully applied to the NASA Hybrid Electric Transit Bus (HETB) project (ref. 1), shown in figure 3. This is a 40-ft transit bus with a unique hybrid drive that includes ultracapacitors, shown in figure 4, for the energy storage system. Ultracapacitors are ideal for this application in that they can repeatedly handle the extremely high charge and discharge currents associated with a heavy hybrid vehicle. At over 37,000-lb gross weight, this is the largest vehicle to ever use ultracapacitor energy storage. Significant efficiency, emissions, and performance improvements were achieved.

Power from both an auxiliary power unit and the energy storage system is delivered to a variable speed electric motor that drives the rear axle. The bus uses regenerative braking to improve fuel efficiency. This technology recovers much of the kinetic energy of the vehicle during deceleration. This replenishes the energy storage system each braking cycle and extends the life of the mechanical brakes.



Figure 3.—The NASA Hybrid Electric Transit Bus (HETB).



Figure 4.—The bank of 30 ultracapacitors installed on the NASA Hybrid Electric Transit Bus.

The HETB met the Department of Transportation (DOT) White Book acceleration specifications.

- 0–10 MPH in 6 sec
- 0–15 MPH in 10 sec
- 0–35 MPH in 21 sec

Fuel economy for a modified Commercial Business District Cycle was 21 percent greater with regenerative braking than without.

Ultracapacitors proved to provide significantly better braking performance than batteries.

- Batteries at ~80 percent State of Charge: full stop in ~157 ft
- Ultracapacitors: full stop in ~103 ft

The work has been expanded to integrate HPM power systems into shuttle buses. Further work was initiated to retrofit gasoline and diesel powered vehicles with HPM power systems.

Electric Bicycles and Wheelchairs

HPM based electric bicycles (refs. 2, 3, and 5), shown in figure 5, and wheelchairs, shown in figure 6, have served as excellent test beds for this technology. The lead acid batteries normally used for these applications have very limited cycle life, poor low temperature characteristics, and the need to be maintained continuously in a charged state. Ultracapacitors can be left indefinitely in a safe discharged state, and then charged rapidly just prior to use. The ultracapacitors will never have to be replaced in most applications. Test results have shown that such HPM based systems can provide excellent performance and reliability. This work has direct application in Exploration based space vehicles, rovers, and surface power systems, as well as numerous terrestrial applications.



Figure 5.—A hybrid electric bicycle was tested successfully with a bank of ultracapacitors for the energy storage system.



Figure 6.—An electric wheelchair was tested successfully with a bank of ultracapacitors for the energy storage system.



Figure 7.—HPM was applied successfully to a human transporter.

Human Transporter

Through an agreement with the GRC TTPO Office and the manufacturer, a human transporter, shown in figure 7, was characterized, and the power system was improved through the application of HPM (ref. 7). The transporter is normally equipped with batteries that require six hours to charge, and must be replaced annually under normal use. For HPM, the vehicle is equipped with ultracapacitors that have unlimited life and can be charged in minutes. In addition to terrestrial applications, this work can be applied to Exploration space vehicles, rovers, and surface power systems.

Utility Vehicle

A lightweight utility vehicle, shown in figure 8, has been successfully utilized as an HPM test bed (refs. 6, 12, and 13). A baseline test was completed with the utility vehicle in its standard commercial configuration with lead acid batteries. The utility vehicle was then tested successfully with power provided only by ultracapacitors. The utility vehicle was then powered by fuel cells, shown in figure 9. The fuel cell powered vehicle utilizes two proton exchange membrane (PEM) fuel cells, with ultracapacitor energy storage, and metal hydride hydrogen storage. The ultracapacitors, shown in figure 10, act as a buffer to provide the transient power required for the vehicle without damaging the delicate fuel cell membrane. The metal hydride hydrogen storage stores the hydrogen in a safe, controlled, manner. This work provides significant experience in advanced power system development for a wide range of terrestrial applications and has numerous applications for Exploration space vehicles, rovers, and surface power systems.



Figure 8.—A fuel cell powered utility vehicle equipped with ultracapacitors.

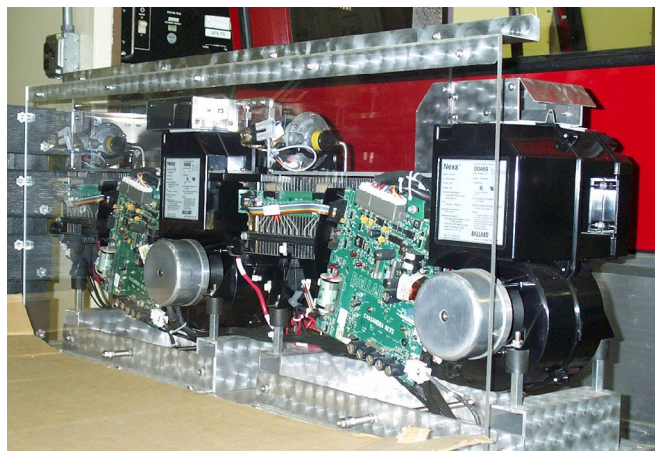


Figure 9.—Proton Exchange Membrane (PEM) fuel cells installed in the utility vehicle.

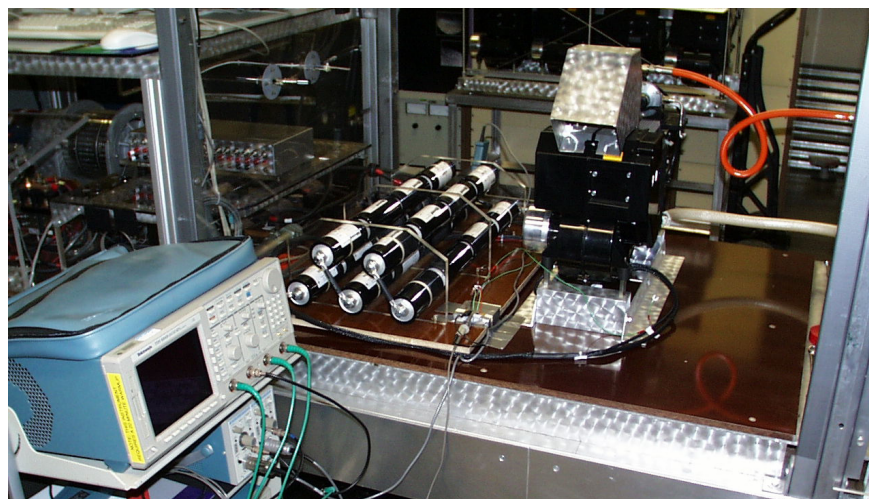


Figure 10.—A bank of 20 series connected ultracapacitors for the utility vehicle.

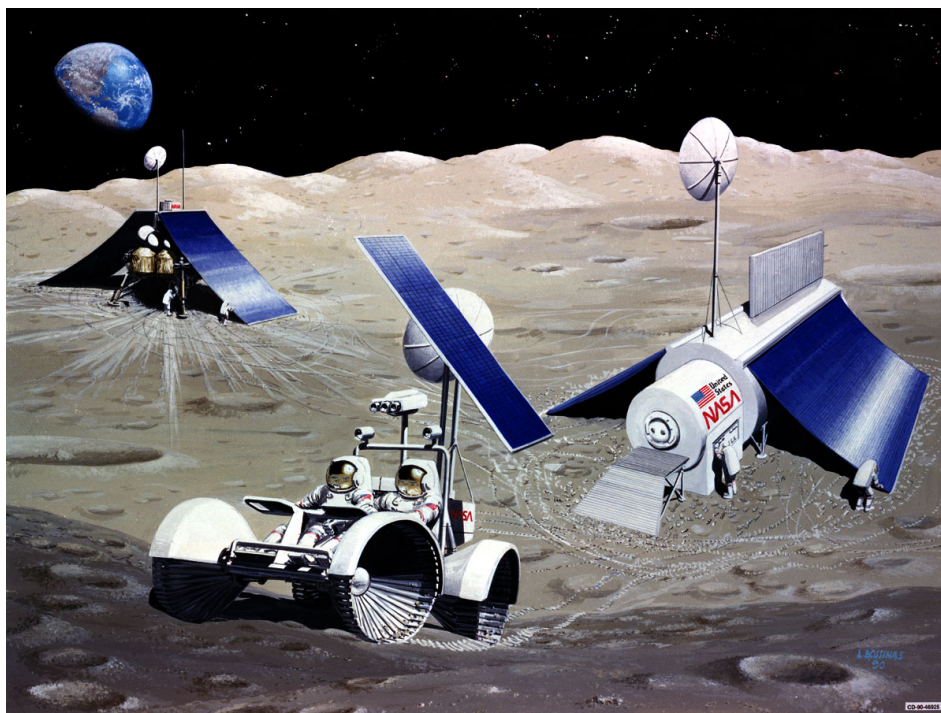


Figure 11.—HPM is being investigated for numerous space exploration applications.

Rovers

The HPM technology developed for the terrestrial applications described is now being applied to the next generation of lunar rovers and other space exploration vehicles (ref. 11), as depicted in figure 11. HPM is ideal for space applications where long life, high efficiency, extreme reliability, and excellent low temperature performance is critical. Many of the HPM components, such as fuel cells, photovoltaic panels, and ultracapacitors, are being integrated into optimal configurations for space exploration vehicles. This work is beneficial for a wide range of Exploration based power systems.

Next Generation Launch Transportation (NGLT)

HPM has been very successfully applied to the Next Generation Launch Transportation (NGLT) Project to obtain empirical data in determining the feasibility of using HPM for the project (refs. 9 and 10). There are large transient loads associated with NGLT that require a very large primary energy source, or an energy storage system. The primary power source used for this test is a proton exchange membrane (PEM) fuel cell, shown in figure 12. The energy storage system can consist of devices such as batteries, flywheels, or ultracapacitors. Ultracapacitors were used for these tests.

Ultracapacitors are ideal for applications such as NGLT where high power density, high efficiency, long life, maintenance free operation, and excellent low temperature performance is essential. State of the art symmetric ultracapacitors, shown in figure 13, were used for these tests. The ultracapacitors were interconnected in an innovative configuration to minimize interconnection impedance.

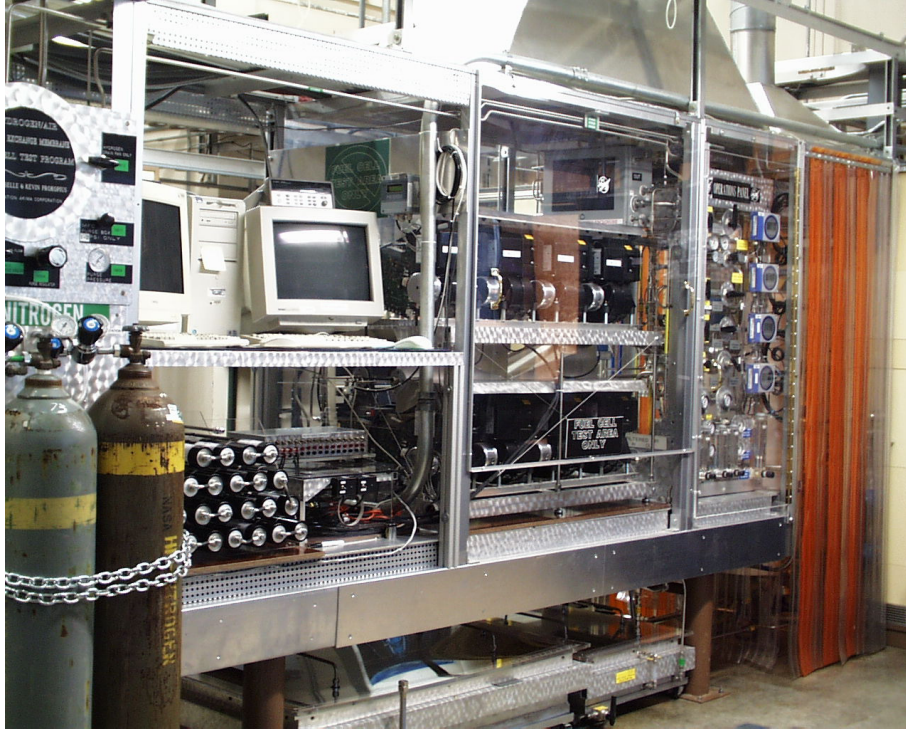


Figure 12.—Proton Exchange Membrane (PEM) fuel cells and ultracapacitors under test at GRC for NGLT.

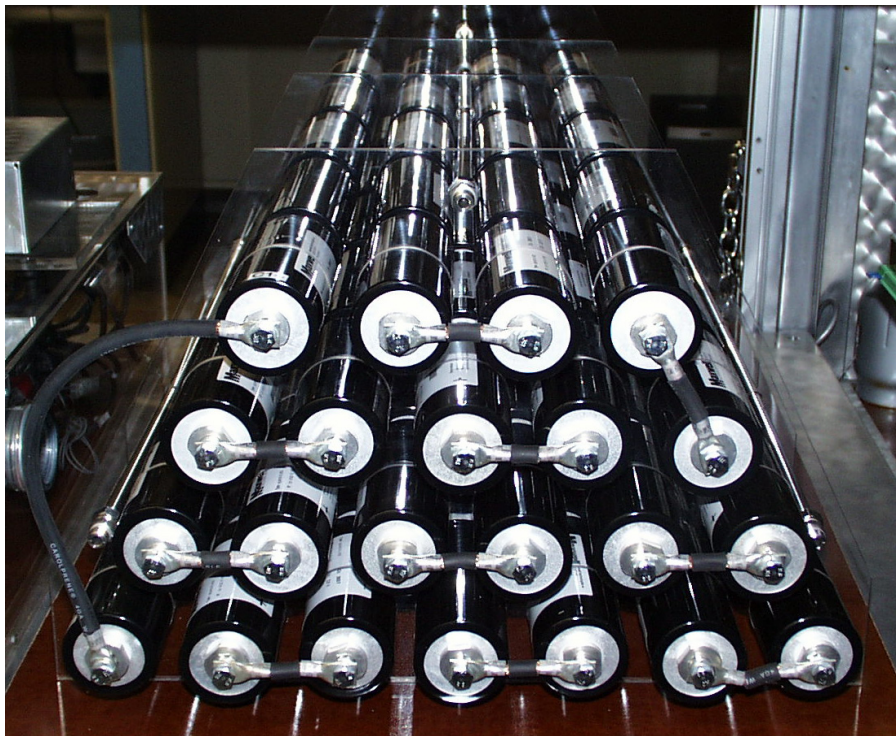


Figure 13.—A bank of 120 ultracapacitors under test at GRC for NGLT.

The life of PEM fuel cells is shortened significantly by large transient loads. Ultracapacitors used in conjunction with PEM fuel cells reduces the transients applied to the fuel cell, and thus appreciably improves its life. PEM fuel cells were tested with and without ultracapacitors, to determine the benefits of ultracapacitors. The implementation of symmetric ultracapacitors in the NGLT power system can provide significant improvements in power system performance and reliability.

Photovoltaic Power Systems

HPM has been successfully applied to photovoltaic power systems (ref. 4). Ultracapacitors complement photovoltaic arrays extremely well. The long cycle life and excellent low temperature characteristics of the ultracapacitors complement the characteristics of the photovoltaic arrays, resulting in a higher performance power system.

A stand alone photovoltaic system was developed, as shown in figure 14 that incorporates photovoltaic panels, ultracapacitors and a sine wave inverter. The photovoltaic panels are mounted on a passive tracking system to improve system efficiency. The ultracapacitors provide short term energy storage. Tests results indicated a significant performance improvement with the addition of ultracapacitors to the system.

A grid-tie photovoltaic system was also developed, as shown in figure 15. The grid-tie system has been an efficient, reliable source of ac power to the GRC utility system. Expansion of the grid-tie photovoltaic system is planned.

HPM based photovoltaic systems are being applied to lunar surface power system designs. The results of this work have wide application for Exploration power system needs.



Figure 14.—An ultracapacitor backed photovoltaic power system at GRC.



Figure 15.—A grid-tie photovoltaic system installed at GRC.

Instrumentation Systems

HPM has been applied to the design of a NASA facility instrumentation system. The instrumentation system utilizes a photovoltaic panel to charge a bank of ultracapacitors. A power converter is used to properly match the instrumentation system to the ultracapacitors, to maximize its capability. The ultracapacitor is able to power the instrumentation system from the ultracapacitors for up to 32 hr, which is completely satisfactory for this application.

The results of this work is useful for Exploration based instrumentation systems, as well as terrestrial based instrumentation systems.

Power Tools

HPM has been successfully applied to power tools and other similar applications (ref. 7). A cordless drill, normally equipped with nickel cadmium batteries, was successfully converted to an ultracapacitor based energy storage system, and is shown in figure 16. This resulted in a cordless drill with an energy storage system that has unlimited life, that can be recharged in seconds rather than hours, has no memory effect, has excellent low temperature characteristics, and that can be left indefinitely in a safe discharged state, and charged when needed. The cordless drill is ideal for long duration space missions, in which the energy storage system can be left discharged, and then charged just prior to use, thus negating any concerns of long mission delays. This work has direct application in Exploration operations and systems.



Figure 16.—An ultracapacitor powered cordless drill.

Safety Equipment

HPM has been successfully applied to highway safety flashers, as shown in figure 17. The flasher utilizes a photovoltaic array for charging a long life ultracapacitor to provide power for dark periods. No maintenance is ever required. HPM has also been successfully applied to smoke alarms, as shown in figure 18. The smoke alarm is normally powered by the ac power system. A bank of ultracapacitors is charged by the ac power system, to maintain alarm power in times of a power failure. The smoke alarm is completely maintenance free. These applications are well suited as a basis for Exploration based safety and power systems.

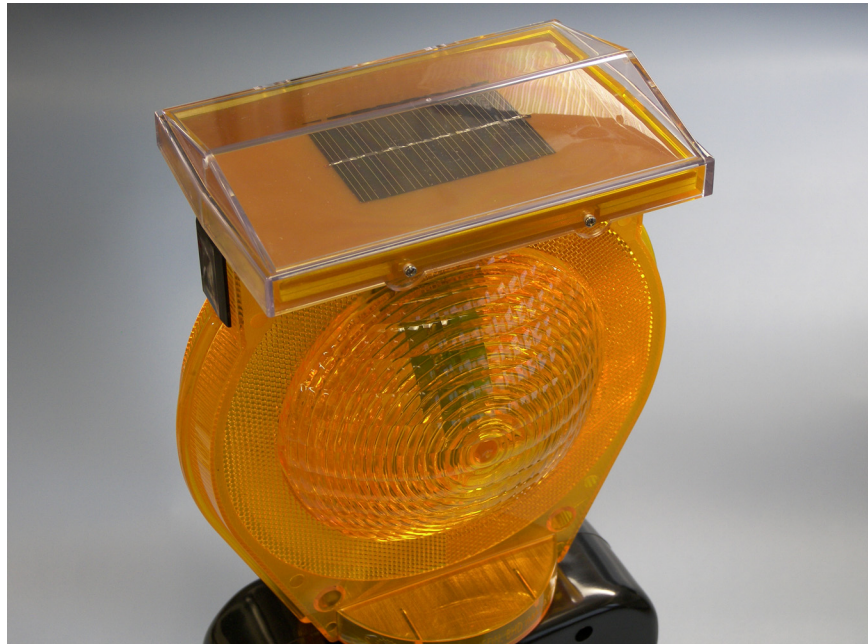


Figure 17.—A hybrid safety flasher powered by photovoltaic cells and ultracapacitors.



Figure 18.—A hybrid smoke alarm powered by utility ac power and ultracapacitors.



Figure 19.—An ultracapacitor powered electric toothbrush.

Health Systems

HPM is ideal for health care where safe, reliable, long life power systems are required. Electric toothbrushes have been developed which operate from ultracapacitors and can be charged in seconds, as shown in figure 19. The ultracapacitors will never need to be replaced in most applications. HPM can be applied to hospital power systems where safe, reliable power is essential. This work is applicable for all space missions.

Space Experiments and Space Vehicles

There are numerous space system applications of HPM that have been implemented, and that are under consideration.

HPM has been applied very successfully to NASA space experiments to provide safe, reliable backup power to the experiment during times when vehicle power is unavailable.

An arm is being considered for the Crew Exploration Vehicle Service Module. Two kW is required for one minute to power the arm, but there is only 300 W steady state available. HPM is being implemented to provide the peak power requirement for the arm. HPM is also being considered to power the Service Module gimbal drive system.

HPM is being applied to satellite actuation to replace unreliable hydraulic systems. The motor and control technology utilized for the HETB has been applied to flywheel dynamometer systems.

HPM has been utilized to provide power for drop tower research, as shown in figure 20. Ultracapacitors can be left indefinitely in a safe discharged state, and can then be charged in seconds, rather than hours, in preparation for the next test. HPM based power systems have been used successfully to power difficult loads, such as high powered lasers.

HPM has wide application in space vehicles, such as shown in figure 21. HPM is being considered for space missions, such as the exploration of the moon and Mars, and deep space missions, such as the exploration of Europa.



Figure 20.—HPM has been used successfully for drop tower research.



Figure 21.—HPM is being investigated for various space exploration applications.

Concluding Remarks

The key element of HPM is the energy storage system. All generated power is sent to the energy storage system, and all loads derive their power from the energy storage system. This technique can significantly reduce the power requirement of the primary power source, while increasing the power system reliability. Ultracapacitors are ideal for HPM based energy storage systems due to their exceptionally long cycle life, high reliability, high efficiency, high power density, and excellent low temperature performance. Multiple power sources and multiple loads are easily incorporated into an HPM based power system. A hybrid power management controller maintains optimal control over each of the components of the entire system. This flexible operating system can be applied to all power systems to significantly improve system efficiency, reliability, and performance.

The numerous successful HPM based applications discussed in this report clearly indicates the extremely wide range of opportunities that are possible with HPM. HPM has the potential to provide significant improvements in space and terrestrial based power systems.

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